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High-Frequency Energetic Particle Driven Instabilities and their Implications for Burning Plasmas

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Three high-frequency modes observed in the DIII-D tokamak have been identified as energetic particle instabilities driven unstable by anisotropic fast ions and runaway electrons. These modes could serve as control tools of the energetic particle distribution in fusion-relevant plasmas. (1) Whistler waves with w»wci, excited by multi-MeV runaway electrons in a low-density (ne~1019 m-3) plasma, have been observed for the first time in a tokamak [1]. The waves occur in multiple discrete frequency bands in the 100-200 MHz range, with the measured whistler frequencies scaling with magnetic field strength and electron density, as expected from the whistler dispersion relation. Whistler activity correlates with runaway intensity (hard x-ray emission level), and a nonlinear interaction between the whistler instability and the runaway electron distribution function is observed. (2) Ion Cyclotron Emission (ICE) is readily excited across a wide region of operational space by kinetic instabilities at harmonics of the main ion wci. ICE is strongest in neutral-beam-heated plasmas with a clear dependence on beam geometry, with the highest emission levels with counter-current beams. This instability responds promptly to transient MHD events, including ELMs, fishbones and sawteeth. (3) Measurements of Doppler-shifted cyclotron resonant compressional Alfvén Eigenmodes (CAEs) below wci are consistent with many aspects of CAE theory, including an onset frequency strongly correlated with magnetic field and the observation of frequency splitting. CAEs are excited on DIII-D when the beam ions are near-Alfvénic, with onset frequencies of ~0.6fci. Consistent with recent hybrid MHD (HYM) simulations [2], a clear threshold behavior of the CAE instability is observed as the neutral beam density is varied at fixed energy. These high-frequency modes can potentially serve as much-needed control tools of the energetic particle distribution in fusion-relevant plasmas: Whistlers as a runaway relativistic electron control during a plasma disruption and ICE and CAEs as passive, non-invasive measurement of the fast-ion activity that could be used to optimize performance. This work was supported in part by the US Department of Energy under DE-FC02-04ER54698.

[1] Spong et al., submitted to Phys. Rev. Lett. (2017).
[2] Belova et al., Phys. Plasmas 24, 042505 (2017).

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